Final Report for Explosives for Lunar Seismic Profiling Experiment (LSPE) NASA T-558A January 29, 1973

Naval Ordnance Lab.

Enclosure (1)

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TABLES

ILLUSTRATIONS

1.0 BACKGROUND

1.1 This is the final report on the "Explosives for Lunar Seismic Pr4filing Experiment (LSPE)" work conducted by NOL for the NASA Manned Spacecraft Center at Houston. The technical work began 7 December 1970. NOL was requested to furnish explosive charges of various sizes for the Lunar Seismic Experiment. This explosive was to have material characteristics identical to those of the explosive previously supplied by NOL for the Active Seismic Experiment (ALSEP). The following tasks were completed:

A. Furnished flight type explosive charges for prototype, qualification, and flight tests.

B. Furnished inert explosive mass simulators with thermal properties similar to those of the flight type explosive. (Both flight and simulator blocks were in accordance with an Interface Control Drawing (ICD) provided by Bendix Aerospace Systems Division (BXA)).

C. Established preferred dimensions of the explosive blocks and established the interface configuration between the blocks,

and the End Detonator Cartridges (EDCs), and the safe/arm plate using the Active Seismic Experiment arrangement as a baseline.

D. Established a safe and reliable safety and arming device and verified safety and reliability by Varicomp testing and by testing of flight type hardware.

E. Conducted design limit environmental tests. The explosive modules for prototype, qualification, and flight tests were assembled by NOL in cooperation with BXA. These modules were subjected to the following environmental test sequence:

i. Acceptance Vibration
ii. Thermal Cycling
iii. Design Limit Vibration
iv. Design Limit Shock

However the flight units were subjected to acceptance vibration only.

F. Assisted BXA in the field testing where NOL:

i. Shipped and installed HE blocks
ii. Planned test program safety where explosives were involved
iii. Installed HE blocks into BXA explosive packa

iv. Defined and controlled overall explosive safety during preparation and conduct of tests

v. Assumed responsibility for field deployment of the explosive package

vi. Defined and was responsible for dud disposal.

The work above applied to two series of tests consisting of prototype and qualification, flight type, explosive packages.

G. Supplied shipping containers and instruments to record temperature and indicate humidity, and three axis shock levels during transportation of HE blocks to Kennedy Space Center.

H. Consulted with MSC/BXA technical representatives on documentation, design, and development test results.

I. Investigated materials which might preclude cracking of the explosive block during acceptance vibration tests.

1.2 MODIFICATION OF STATEMENT OF WORK FOR LSPE. The following additional tasks were also accomplished:

(a) High speed photographic data on two lots of end detonating cartridges, L/N CNH and L/N CTN were obtained.

(b) Functional tests of two flight hardware explosive trains including EDC's, leads, and explosive blocks at an ambient pressure of 1×10^{-3} Torr or less were made.

(c) Explosive leads for prototype, qualification and flight S and A devices were designed, developed and fabricated.

(d) A document for the flight environmental test plan and procedure was issued.

(e) Test design limit temperature cycling of the HE block was changed to the MSC limits.

(f) Test support and materials needed to detonate up to 10 approximate 1-lb TNT charges at a distance up to 1,000 feet from the central control station were provided.

G. The following milestone delivery dates were met:

i.	Preliminary HE and S/A design	Oct 1970
ii.	Sign-off by BXA/NOL ICD for HE and S/A	Nov 1970
iii.	Delivery of inert prototype models to BXA	Apr 1971
iv.	Delivery of prototype models for field test	Jan 1971
v.	Delivery of qualification models for field test	Oct 1972
vi.	Delivery of flight models to Kennedy Spaceflight Center	Nov 1972

2.0 PROGRAM LOGISTICS

2.1 The logistic flow of the prototype hardware is shown in Figure 1. The explosive charge housings with all-mass simulators were shipped to NOL and assembled to the explosive charges. The explosive charge assemblies were then shipped to the Naval Weapons Laboratory, Dahlgren, Virginia (NWL) for environmental testing. Environmental testing was accomplished with EP's attached to a transport frame as shown in Figure 2. The explosive packages were then sent to NASA, White Sands Test Facility (WSTF) where they were integrated with the Electronic and Safe/Arm Mechanism (E&SA's) and finally deployed.

2.2 The flow of hardware at WSTF (Figure 3) was covered by special instructions (TPS) which alerted WSTF personnel as to the safety hazards in handling and storage of the explosive charges. The TPS was written in the field by NOL. Abnormalities such as detonation

of the standard TNT calibration charge and dud disposal were covered by the WSTF Field Test Safety Plan.

2.3 The explosive charges for flight were shipped directly from NOL to Kennedy Spaceflight Center (KSC). Final assembly of the E&SA to the explosive was made at KSC by NOL.

3.0 PROCUREMENT OF BULK EXPLOSIVE

3.1 A request for bid (RFB) for 200 lbs of Hexanitrostilbene (HNS-II)[1,2] Grade A, dated 17 Dec 1970 was sent to three potential bidders. The important terms in the RFB were:

a. All of the 200 lbs had to be supplied in one uniform lot.

b. A certificate of compliance to the specification (WS5003E) had to be submitted. Acceptance was subject to verification by tests by NOL.

c. Delivery was to be at destination within 37 days after date of contract.

d. Required delivery at destination had to be within 44 days after date of contract.

3.2 HNS-II explosive was received from Del Mar Engineering for the preparation of the blend, HNS-II/TEFLON 90/10. It was procured under the NOL Weapon Specification, WS5003E, according to the quality

assurance inspection plan for the LSPE prototype hardware. Final acceptance of the explosive was to be contingent on the results of NOL testing. The explosive was tested at NOL according to WS5003E and was found to be deficient in the following areas:

a. Test Procedure (Para. No2) 4.5.1.2
Vacuum Stability (a) ml/gm for first 20 minutes
Allowable 0.6 ml max. NOL Findings: 0.8 ml

b. Test Procedure (Para. No.) 4.5.1.4
Water-soluble material, % by wt
Allowable 0.03% max. NOL Findings: 0.14-0.15%

c. Test Procedure (Para. No.) 4.5.1.5
Insoluble material, % by wt
Allowable 0.03% max. NOL Findings: 2 samples 0.02%
3 samples 0.03, 0.04,
and 0.04%

All other properties were acceptable, i.e., melting point, melting range, vacuum stability for an additional two hours, surface moisture, bulk density, and explosive sensitivity.

3.3 In view of the above findings, NOL considered the failure of the 20 minutes surge test as a very minor exception from the specification. The water soluble material was not expected to affect the performance or the thermal stability. In fact, in the HNS-I portion

of the specification, the allowable water soluble material was 0.2%. The deviation in % soluble material was probably not much more than the experimental error involved in making the measurement. Since the temperature envelope proposed by NASA/MSC was not expected to exceed 150°C, and the specification WS5003E was designed to qualify HNS to a temperature of 200-230°C there was no property of this explosive (Del Mar Engr. 200 lbs of HNS-II) that would present any problems to the LSPE program.

3.4 The above information was transmitted to MSC as a request for deviation from the specification, WS5003, and from the quality assurance test plan for prototype hardware. NASA concurred but limited the use of the material to prototype hardware only at that time. However, the entire lot was blended in anticipation of subsequent approval for use in qualification and flight hardware.

3.5 The small scale gap test sensitivity[3] was determined for a representative batch of HNS-II (ID. 1479). The results were analyzed by the Bruceton test method as per WS5003E. The HNS-II sample at the specification acceptable density of 1.629 g/cc had met the sensitivity and output requirements of WS5003E.

3.6 As reported in earlier progress reports, the 150 lb of HNS-II purchased from Chemtronics (Chemtronics Lot 36-44) did not pass the bulk density test. It was returned. A new lot was sent to NOL for acceptance testing. This lot (Chemtronics Lot 36-45) was given the NOL identification number X-774. A representative sample was taken

from this 150-lb lot. Quality assurance tests were conducted as required by WS 5003E. All of the requirements as specified in WS 5003E were met for the following specification tests:

(i) Melting point range

(ii) Vacuum Stability

(iii) Surface Moisture

(iv) Water Soluble

(v) Insoluble Material

(vi) Bulk Density

(vii) SSGT Sensitivity

(viii) Output

4.0 DIFFERENTIAL THERMAL ANALYSIS ON HNS, TEFLON, AND HNS/TEFLON 7C 90/10

4.1 Differential thermal analyses were run on HNS (X756), HNS/Teflon 7C (X757 and ID 1462), and Teflon 7C. Heating rates of both 5°C/min and 10°C/min were used on all materials except HNS/Teflon 7C (ID 1462), which was run only at the 5°C/min heating rate.

4.2 All of the HNS and HNS/Teflon samples showed a slight exotherm (believed to be due to decomposition) just prior to the endotherm due to melting.[4] The temperature range of the initiation of the melting point endotherm was 311.5°C to 312.5°C for HNS (X756), 311.0°C to 311.8°C for HNS/Teflon 7C (X757), and 325.5°C to 328.6°C for Teflon 7C.

5.0 INERT EXPLOSIVE SIMULANT FOR HNS/TEFLON 90/10 WITH THERMAL PROPERTIES

5.1 One of the requirements of the project was to develop simulant compositions and manufacture inert explosive charge simulator blocks for Bendix to be used in some of their in-plant tests. It was desirable that the physical properties of the simulant be as similar as possible to those of HNS/Teflon. A number of such simulant compositions were developed and evaluated. A summary of these compositions is given in Table 1.

5.2 A number of materials were evaluated in an effort to develop an inert simulant possessing the same density and thermal properties as pressed HNS/Teflon. The most promising formulation was a pressed mixture of melamine, kaolin, and Teflon which was thermally stable at 150°C, had the same density as HNS/Teflon, and was machinable.

5.3 The thermal diffusivity (from which the thermal conductivity is obtained) and specific heats have been obtained for HNS/Teflon-30, HNS/Teflon-7C, Teflon, and simulants 10, 12, 14, and 15 of Table 1. The results of these tests indicate that a simulant can be made within the specification limits shown on the Bendix drawings. These test results are detailed in Table 2.

5.4 The coefficient of linear expansion has been run on virgin Teflon and on one lot of HNS/Teflon-7C.

5.5 Experimental charges have been pressed and machined. Eighty (80) charges of HNS/Teflon of various sizes and densities were made, as well as thirty-nine (39) charges of various kinds of simulants. The inert simulant selected was:

Melamine (Eastman 1540 or equivalent)	10.0 ± 0.5%
Teflon (DuPont 7C)	24.0 ± 0.5%
Vinylidene fluoride resin (Pennwalt RC 2525)	66.0 ± 0.5%

5.6 THERMAL PROPERTIES. The thermal conductivity and specific heat of the selected composition (designated as Simulant 20) were 5.793×10^{-4} cal/cm/sec-°C and 0.278 cal/gm/°C, respectively. These compare favorably with the values of 5.636×10^{-4} cal/cm/sec-°C and 0.249 cal/gm/°C obtained for HNS-II/Teflon-7C (ID 1462) made from HNS-II (x580) remaining from the ALSEP program. The coefficients of linear thermal expansion were obtained for virgin teflon, HNS/TEFLON-7C (ID 1462), and each of the components of the selected simulant. A value of 6.68×10^{-5} cm/cm/°C was obtained for the HNS/Teflon-7C (ID 1462). Details of this and the other measurements made are given in Table 3. During the thermal cycling required to make the coefficient of linear thermal expansion measurements, irreversible growth of some of the materials was found to have taken place. Although this growth ranged up to 1.67% (percent increase in length) for the melamine, it was less than 0.1% for the HNS/Teflon-7C. The percent of irreversible growth experienced[5] on the initial temperature cycle is given in Table 3.

5.7 COMPRESSIVE STRENGTH TESTS. Compressive strength values have been obtained on pellets made from HNS/Teflon-30 machinings from the ALSEP charges (ID 1378) and HNS (X580)/Teflon-7C (ID 1462) molding powder. Pellets from each batch were made at two different compaction pressures. The effect of temperature cycling of these pellets was also examined. The increase in compressive strength due to temperature is readily apparent from the data as shown in Table 4.

6.0 DETONATION VELOCITY MEASUREMENT OF HNS/TEFLON 90/10 ON THE STREAK CAMERA

6.1 A single five (5) pound charge of HNS-II/Teflon-7C was fabricated from the first 10-pound batch of explosive made by the new process (dry blend). It was pressed into a cylinder at 25 K psi in a double ended mold using an isostatic press and machined to a diameter of 5".002 and a length of 4".185. The charge weighed 2282 gms and had a very uniform, light yellow color. Its density was 1.693 g/cc. Upon firing, the charge was viewed by a Cordin high speed camera. Initiation was with an EDC detonator held in a fixture located on the flat end of the cylindrical charge. This allowed the EDC to fire over a 0.374-inch air gap before striking the charge. The detonator was off-set from the charge axis, being 1-1/8 inches from the closest cylinder side. A 0".125 wide x 0".100 deep slot through the bottom of the detonator fixture allowed observation by the camera of detonation products as they struck the HNS charge.

The Cordin high speed smear camera was writing at 3.0 mm/μsec. The smear camera slit recorded detonation arrival along the cylinder surface and across the end surface opposite the detonator. (See Figure (4).)

6.2 The results of the shot were as follows:

(a) Detonator response time: 38 μsec. (This was the time between application of a 2.5 KV pulse (4mfd) to the detonator and the arrival of detonation products at the HNS charge.)

(b) The first products from the detonator crossed the air gap between the detonator and the HNS/Teflon surface at a rate of 3990 meters per second.

(c) Detonation velocity based on measured arrival times along the side of the cylinder was constant at 6990 m/sec.

(d) Average detonation velocity based on arrival time at the cylinder face opposite the detonator was also 6990 m/sec.

6.3 Analysis of shock wave arrival profiles indicated that detonation was obtained close to the input surface of the charge and over a region (probably related to the diameter of the hole through the detonator holder) rather than at a single point. Build up to detonation was rapid. Full scale detonation was achieved by the time of wave arrival at the side of the cylinder nearest the detonator, i.e., after less than 1-1/8 inches of travel. The values of

detonation velocity obtained through the charge and along the surface were identical in this test, again indicating that a steady state was readily established in the charge.

6.4 Two charges of HNS-II/Teflon 90/10 plastic bonded explosive were fired and viewed by high speed photography. Initiation was by an EDC (Flight Unit) detonator located on a flat end of the cylindrical charge and acting over a 0.375-inch air gap. The detonator was off-set from the charge axis. One charge weighed five pounds (2268 g), had a diameter of 5.007 inches, and a height of 4.185 inches (density = 1.679 g/cm^3). The center of the detonator was 1.125 inches from the edge of the charge. The other charge weighed one pound (445.5 g), had a diameter of 2.750 inches, and a height equal to the diameter (density = 1.664 g/cm^3). In this second shot, the detonator was located 0.96 inches from the charge axis. The detonator was energized by the sudden discharge of a 4 microfarad capacitor charged to 2500 v. Observation was by smear camera writing at a rate of approximately 3 mm/μsec. A bridgewire located in the field of view of the smear camera was exploded at the same instant that the detonator was energized. The time elapsed between the bridgewire flash and the arrival of detonation at the far end of the charge, along with the propagation rate through the charge only as determined by the smear camera, serves to determine detonator delay, i.e., the time required for the transit of detonation through the charge only was subtracted from the total time to give the detonator delay. The arrival of detonation was recorded along both the side

closest to the detonator and across the end of the charge opposite to the detonator. From the relative measured arrival times the average detonation velocity was obtained between any two detonation paths.

6.5 The results with the five-pound charge (NOL Shot No. D-174) show that the detonator delay was 34 $\pm$ 0.33 μsec and that the average detonation velocity was 6800 - 6950 m/sec determined from side arrival and 7000 - 7100 m/sec from end arrival. The results with the one-pound charge (NOL Shot No. D-176) show that the detonator delay was 4.0 $\pm$ 0.23 μsec and that the average detonation velocity was 6650 - 6700 m/sec by side arrival, and 6850 - 6950 m/sec by end arrival. Apparently, the difference between side- and end-derived velocities is due to the gradual increase in detonation velocity as the detonation moves through the charge. Probably the difference in maximum detonation velocity obtained in the two shots is due mostly to the difference in loading densities. From the limited results obtained, the initiation of the charges seems to be reliable, but there was some evidence, based on detonation-trace intensity, that the higher density (larger) charge was not building up as quickly in the first part of the detonation trace as the lower density charge. This is compatible with the usual behavior of high explosives in that a lower density charge would be more sensitive to shock initiation but have a lower detonation velocity. It appears, however, that in both cases the maximum detonation velocity was reached for all practical purposes by the time the detonation front neared the far end of the charge.

6.6 As was pointed out, the explosive train was redesigned to incorporate a new HNS lead. The lead was necessary to improve the reliability of initiation of the HE block. The detonation of an HNS/TEFLON (90/10) charge initiated by the redesigned explosive train was observed with the Cordin streak camera and compared with the results of a similar test on the lead-less system mentioned earlier.

6.7 The charge in this test was a 4.875-inch diameter by 4.874-inch long cylinder of explosive isostatically pressed and then machined. Its density was 1.696 g/cc. The HNS lead, mounted in the S/A slider, was initiated by an end detonating cartridge from NASA lot CNH. The detonator was located on one end surface of the cylinder; its center was 1-1/8 inches in from the closest cylinder side. The camera record included detonation arrival profiles from the closest cylinder side, the most distant side, and also from the end of the charge opposite the detonator.

6.8 The detonation velocity obtained was 7000 meters/sec (essentially identical to the 6990 meters/sec obtained with the lead-less system). The "effective center" of initiation was about 6 mm back of the charge surface, implying that initiation occurred close to the back surface of the charge and over a region (probably related to the diameter of the hole at the output side of the lead holder) rather than at a single point.

7.0 EXPLOSIVE PACKAGE ENVIRONMENTAL TESTING

7.1 NOL sub-contracted the environmental testing of the explosive package to the Naval Weapons Laboratory, (NWL) Dahlgren, Virginia. This was done for reasons of safety (explosive quantities exceeded limits for NOL facility) and for lack of certain vibration equipment in the NOL explosive test area.

7.2 Two sets of prototype hardware (16 explosive packages) completed the environmental test sequence at the Naval Weapons Laboratory at Dahlgren, Virginia. This test sequence was defined in the NOL statement of work, paragraph 4, and the modifications to the work statement, attachment 2, paragraph e as (a) acceptance vibration, (b) thermal cycling, (c) design limit vibration, and (d) design limit shock.

7.3 The environmental testing was accomplished in various phases with the explosive section of the experimental package tested separately from the electronics during the program. Mass simulators were used to replace actual electronics and timing mechanisms. A typical test vehicle is shown prior to assembly in Figure 5A. Note the foam fill used to reduce the air volume where the various size explosive charges were used. The assembly is shown in Figure 5B.

7.4 Since the explosive packages were to be transported to the lunar surface attached to a transport frame, the explosives were

tested attached to the transport frame for proper simulation. A typical set of 8 charges is shown attached to these frames in Figure 5B. The program for sequentially testing the prototype hardware is described in the four categories below.

1. Thermal Cycling (Design Limit) -

The packages were exposed to the following time/temperature profile:

Reduction of temperature from ambient to -100°F (0-3 hrs)
Raise temperature to -40°F (3-6.5 hrs)
Raise temperature to 250°F (6.5-11.5 hrs)
Reduce temperature to 190°F (11.5-16 hrs)
Reduce temperature to -100°F (16-18 hrs)
Raise temperature to Ambient 75°F (18-24 hrs)
(times are the elapsed times from the beginning of the thermal cycle sequence)

The packages were X-rayed before and after the thermal cycle. It was noted on the radiographs following the tests that cracking occurred in the larger charges. Further investigation revealed that the 1/2, 1, 3, and 6 pounds charges showed various degrees of cracking brought about by the thermal cycle. In the cubical geometry the cracks were both vertical and cross-axis to the charge. The cylindrical charges all exhibited the same cross-axis cracking.

At this point several questions began to arise as to whether a charge could be fabricated to withstand this thermal shock without

cracking and whether there should be a question of safety and reliability associated with the cracking phenomena. A literature search revealed little on the effects of cracks on the safety in handling or the performance of an explosive charge containing fissures. NWL was authorized to continue the environmental testing of the cracked charges after which time NOL selected five cracked charges for camera study. These charges were replaced with newly fabricated prototype charges for field testing.

2. Acceptance Vibration -

The specification for this test was to vibrate from 5-12-100 hz @ 0.15" D. A. or 1.0 G peak at 64.5°/minute. The transport frames were vibrated on three (3) orthogonal axis with the maximum running time of 1.4 minutes for each axis.

A review of radiographs following X-ray revealed no additional cracking or powdering of the explosive.

3. Vibration Tests (Design Limit)

The units were then subjected to the following vibration test:

a. Vibrate 5-1000-5 hz @ 0.2" D. A. @ 64.5°/minute with a crossover at 1.4 G and continue to sweep at 1.4 G. Subject to one

complete cycle only up and down. The approximate running time was 2.9 minutes. The units were tested on three (3) orthogonal axis using the above values.

b. Vibrate at 6 hz, 1.5 G for 10 seconds on each axis.

c. All units were vibrated, for random noise, to the following specification:

20-40 hz	12db/octave increase
40-85 hz	0.03 G^2/hz
85-110 hz	6db/octave increase
110-400 hz	0.05 G^2/hz
400-460 hz	6db/octave
450-1100 hz	0.04 G^2/hz
1100-2000 hz	12db/octave

The total time for each axis was 1 minute.

4. Shock Testing (Design Limit)

Each unit was subjected to shock on each axis at 15 G peak sawtooth with each having a 10 millisec rise to peak and 1 millisec fall for a total duration of 11 millisec.

7.5 The results of the environmental tests indicated the following:

a. The transport frame, the structure which retains the explosive charges during vibration, yielded after being subjected to shock.

b. Cracking and one lug failure were observed on the antenna collars after shock testing.

c. No abnormalities were observed after design limit vibrations.

d. The antenna collar cracked on the explosive package during the thermal test.

e. The explosive charges cracked following the thermal cycling. The 3, 1, 1/2, and 1/4 lb charges (total 8) exhibited cracks as revealed by radiographs before and after the test. The cracks were not expected to degrade the performance of the explosive. (A group of five of the above charges (3, 1, 1/2, 1/4, 1/8 lb) were fired to determine their detonation velocities.)

The X-rays following these tests revealed no additional fissures over the original ones caused by the thermal shock. It was concluded that:

(i) The test environment was not fully representative of the mission.

(ii) The thermal gradients caused the cracking of the charges.

It was pointed out by NOL that the cracks would not affect the performance of the explosive charges in the field. A program was recommended to confirm the performance of several of the cracked charges by detonating them before a high speed camera and measuring the detonation velocity along the side of the charge.

8.0 EXAMINATION OF THE PROTOTYPE HE CHARGE CASE AND THE 6-LB EXPLOSIVE CHARGE AFTER ENVIRONMENTAL TESTING

8.1 There were two action items resulting from a BXA/MSC/NOL meeting:

(1) NOL/BXA were to examine the eleven remaining charge cases (of the 16 tested at NWL) for cracks and other anomalies.

(2) NOL/BXA were to examine the top surface of the 6-lb explosive charges for type and number of hairline surface cracks.

8.2 A visual examination of the cases and charges was made and reported on a preliminary basis to BXA and MSC. A BXA representative was sent to NOL to witness the points of interest. The results of the examination were as follows and should be considered as "closing-out" the action items:

8.3 Charge Case Examination:

(a) Charge EP1; C/N-8:

A hairline exterior crack in the paint was observed on the side of the HE container. The crack was sharp and well defined. The electroplating near the crack was carefully removed revealing stress lines in the fiberglas case. It was impossible to state whether the fiberglas housing itself was cracked. The HE case showed no additional defects.

(b) Charge EP1; C/N-16:

No anomalies or defects were noted.

(c) Charge EP2; C/N-2:

No surface cracks were noted. However, some blistering of the thermal paint occurred.

(d) Charge EP3; C/N-9:

Small chips of thermal paint were missing from the bottom of the HE housing. No flaking was observed near these chips or anywhere else.

(e) Charges EP4; C/N-4 and C/N-14:

Some smear of adhesive (or comparable material) was noted around the upper edge of the HE case. In both charges it had collected around the screw pictured. This material has either reacted with the thermal paint or/and caused it to flake off the electroplating at the upper edge of the case. No flaking was observed on any of the four painted sides of the case.

(f) Charge EP5; C/N-5:

The same material, as in (e) above, was noted near the top of the HE housing (approximate size $\cong$ 1" x 1/2"). This material was also noted at about 1-1/2" from the bottom of case (area $\cong$ 1/2" x 1/2"). All thermal paint was intact with sub-surfaces.

(g) Charge EP6; C/N-12:

No anomalies were noted.

(h) Charge EP7; C/N-11:

One area was void of thermal paint, exposing the electroplated material. In addition, a crack in the fiberglass was also noted. This crack appears to have eroded. This crack is in the same location as the crack observed on Charge EP1; C/N-8. In both these charges, the original

phillips head screw was replaced by a set screw to facilitate assembly of the charge to the transport frame. Both charges (and cracks) were located on the left hand side of the transport frame.

(i) Charge EP8; C/N-7:

Some blistering of the paint was observed about 1/2" from the top of the case. (Reaction similar to that noted on Charges EP4; C/N-6 and C/N-16.)

(j) Charge EP8; C/N-15:

No anomalies were noted.

8.4 The top surfaces of two 6-lb charges were examined for size and type of cracks which resulted from the thermal cycling tests. In general, several hairline cracks were observed on each charge, and one had a width of approximately 0.005 inches.

8.5 Considerable effort went into the fabrication of the explosive charges at the Naval Ordnance Laboratory and included studies to determine the compressive strength and the thermal properties of the HNS/Teflon 30 and the HNS/Teflon 7C. The cracking phenomenon[6] in explosive charges both castings and pressed charges was not new but has been only minimally covered in publications. One publication pointed out that the length and width of the cracks and

the weight of the explosive effected the formation of a high pressure jet in an explosion. However, there was no indication of the explosion not propagating across the crack as required here. Deleterious effects would depend on the performance required of the explosive, i.e., whether it is a simple explosion, a wave shaping explosion, or perhaps an explosion to cause the formation of metal jets for penetrating or cutting metal targets. In view of this it was decided that for an explosive used to produce simulation of a seismic shock wave, any jetting or irregularities in the induced wave would not detract from the explosive's effectiveness. There appeared to be no safety problem associated with the environmental design limit profiles. By the same reasoning, there certainly would be no safety problem associated with the space mission from earth to the moon and throughout the lunar deployment.

8.6 On the question of reliability of the explosive train functioning, one charge of each explosive weight (including 1/8- and 1/4-lb uncracked charges) was tested before a streak camera to determine if the detonation wave was degraded or thought to be unreliable because of the cracking or exposure to various environments. There was no indication, from the results, of any fading or decay in the shock velocity associated with any of the charges which had been subjected to environmental testing. A reduction of the data indicated a detonation velocity of 6900 m/sec which is comparable to that obtained from the units which were not subjected to the testing. The camera study was conclusive, but in the final

analysis field testing of these units with a complete electronics and safe-arm device was required.

8.7 The complete unit was assembled in the field and tested. The explosive packages were deployed and tested according to a test plan which simulated expected distances of travel on the lunar surface and experimental parameters for the LSPE (Lunar Seismic Profiling Experiment).

8.8 Five prototype explosive charges previously thermally cycled in environmental testing were tested for detonation velocity using the streak camera. The four largest of these explosive charges (3,1,1/2, and 1/4-lb sizes) were cracked by the thermal cycling. The detonation velocity was of interest as an index to proper functioning. A summary of the resulting data is shown in Table 5, and the streak camera test arrangement in Figure 4.

8.9 The detonation velocities obtained (in four of five trials) ranged from 6,620 to 7,020 meters/second. These velocity values were considered to be in fair agreement with the previously obtained values of approximately 6,990 meters/second. The streak camera trace for the 1/8-lb charge was lost, but the charge did initiate, and indications were that it did detonate.

9.0 FIELD TESTING OF PROTOTYPE HARDWARE (NASA, WSTF)

9.1 STANDARD CHARGE TEST. The Naval Ordnance Laboratory, as a part of the MSC Statement of Work, was asked to support the first test shot both with materials and personnel. This shot consisted of deploying a 1-lb TNT block at a distance of about 10 meters south of test site #1 (refer to Figure 6) between site #1 and geophone #4. The explosive charge was placed on firm ground with sandbags between the charge and the LSP Test building. The test sequence followed the standard charge detonation countdown procedures. The charge was deployed and detonated according to the NOL Y.2 test procedure and the BXA Field Test Safety Plan.

9.2 ASSEMBLY OF PROTOTYPE HARDWARE. Following the E & S/A functional procedures performed by BXA, the NOL team removed the inert explosive package and assembled a 1/8# explosive charge to the E & S/A which incorporated the antenna. All explosive assemblies took place in the EP assembly trailer shown in Figure 6.

9.3 After the explosive package (Figure 7) was assembled according to the WO/OP sheets, the environmental cover with heaters installed was assembled to the EP. The flash bulb EDC monitor was installed as the last item prior to storage in a fuze can. The fuze can and explosive charge were stored at 60°F in the trailer until final deployment. Bendix Quality Control witnessed all operations.

9.4 The charge was deployed at test site #13 according to the LSP countdown procedures. A plywood barricade was installed prior

to deployment to keep animals away from the explosive packages. The timers "timed-out" and the explosive package SN 12 detonated as intended about 92 hours after its deployment.

9.5 All explosive packages were fabricated in the same way as SN 12. Deployment of each package was made such that all detonations would take place between 12:00 midnight and 7:00 A.M. The SN 15 (1/8#) explosive charge was placed under a BXA fragmentation dome, designed to collect the fragments from the exploding package. Collected fragments could then be analyzed at a later date. The dome shot took place on test site #1. The 1/4# shot was deployed 500 meters from geophone #4 at test site #3. The 6# charge was deployed 3.5 KM from the #4 geophone. All shots timed out as expected between 0100 and 0500.

9.6 As a part of the NOL support to the field tests, the E & S/A's were removed from the inert housings after the functional procedures were performed. The explosive charges were attached to the E & S/A's; the environmental covers were placed over the units and stored at room temperature in the pyrotrailer. The charges were deployed on March 23, 1972 so the time-out periods would be completed by March 27 at 0200, 0300, 0400, and 0500 hours; the best times for low RF and seismic noise levels in the designated test area.

One of the tests, SN7, was the 1/4-lb shot under the BXA supplied dome. The explosive package was placed under the dome with proper orientation to collect fragment data. This shot failed to detonate.

9.7 The BXA/MSC/NOL back-out logic, Figure 8, for the WSTF was used. The transmitter was turned off 3 hours after the package did not fire. Because of darkness, the next step in the back-out logic was delayed for 3 more hours. The NOL/WSTF/BXA team determined that the slide mechanism had moved into the resafe position and the flash bulb had not fired. The team left the field and following a conference with the test director, wrote the necessary TP's to cover the removal of the dome from the package. The dome was removed. NOL disassembled the charge and placed the E & S/A and the HE charge in separate boxes for removal from the test site. Both units were returned to the pyrotrailer for disposition by MSC/BXA.

9.8 The same type of problem occurred with the 6-lb charge, SN10. The same back-out logic was used for that charge. The package was disassembled and returned to the pyrotrailer for disposition by BXA/MSC. The timers which failed were returned to BXA. A complete timer redesign was made before the remaining proto tests were completed.

The 1/4-lb and 1-lb packages detonated within the expected time frame.

9.9 Following a complete redesign of the Bulova timers, new prototype packages were assembled and sent to the field. Two of the explosive packages SN7 and SN10 were rebuilt and sent back to the field along with SN8. Within this time frame BXA was requested to instrument two fiberglas/styrofoam domes to make a determination of

the fragment velocities of the package and its associated hardware. The SN7 and SN8 packages 1/4-lb and 1/8-lb explosive charges, were successfully tested as dome shots. The last prototype explosive charge tested was the SN10, 6-lb unit.

10.0 FIELD TESTING OF QUAL HARDWARE (NASA, WSTF)

10.1 The field testing of the qual charges was accomplished by deploying four charges in a single group and allowing each to time out and detonate. A second set of four charges followed the same sequence; all with successful detonations.

11.0 ASSEMBLY OF FLIGHT HARDWARE AT KENNEDY SPACEFLIGHT CENTER

11.1 NOL assembled the flight hardware at Kennedy Spaceflight Center as a part of the field support to the LSPE task. The assembly was made per TCP 2368938 written by BXA and observed by BXA and NASA quality control personnel. Eight explosive packages were assembled and checked out by NOL. Final touch-up of paint etc. and assembly to transport frames was accomplished by BXA. The transport modules were placed aboard the APOLLO 17 Spacecraft on November 28, 1972, to be transported to the lunar surface after December 6, 1972.

12.0 DETERMINATION OF FRAGMENT VELOCITY OF CASE OF EXPLOSIVE CHARGE

12.1 At the request of NASA/MSC, NOL exploded a one-pound explosive package before a Jacobs framing camera and determined the fragment velocity of the case confining the charge. The films were read on a Vanguard enlarger and the data reduced to give initial velocities of the fiberglas case in three directions. The initial

velocity toward the antenna was 10,400 ft./sec.; away from the antenna, 5200 ft./sec.; and downward (toward the lunar surface) 11,150 ft./sec. Product gases obscured any record of motion of the mechanical and electronic portions of the package. This information was presented to MSC as an input to the LSPE explosive package hazard analysis.

13.0 CONCLUSIONS

13.1 In assessing the overall question of cracked charges, there was no significant difference in the thermal properties of the HNS/Teflon 30 and HNS/Teflon 7C. However, there was an improvement in the compressive strength of the TEFLON 7C test specimen. It should also be pointed out that some improvement in compressive strengths was accomplished with both blends of explosive/TEFLON by submitting the specimens to a thermal cycle after fabrication. There was some irreversible growth experienced during the initial cycle. There appears at this time to be no obvious way to improve on the strength of an explosive charge fabricated from HNS/Teflon 7C. From the basic knowledge and experience with explosives, scientists find that nearly all large explosive charges crack after fabrication, either simply from the aging of the explosive or by some mechanism of thermal shock. There has been little knowledge conveyed in this area, but the concensus was that cracks in explosive charges do not affect either their safety in handling or their reliability of functioning.

13.2 The detonation velocity measurements with the streak camera indicated a stable detonation in the HNS/TEFLON 7C explosive charges. The cracks in the large explosive charges following thermal cycling did not affect their performance.

13.3 The results of the compressive strength tests showed the TEFLON 7C to be a better binder than the TEFLON 30. From a materials handling viewpoint, the TEFLON 7C was better because a dry blend could be prepared and did not require the volumes of water for washing as was associated with the TEFLON 30.

13.4 It was determined from the test results of thermal cycling, acceptance vibration, design limit vibration, and design shock[7] that the cracked explosive charges fabricated from the HNS/TEFLON blend were safe to handle.

13.5 The field tests and streak camera tests indicated these charges would perform satisfactorily after being submitted to the environments expected furing the lunar mission.

Acknowledgements:

The author wishes to acknolwedge the explosive sensitivity data collected by L. Montesi,[8] blending procedure by C. Meisner,[9] thermal properties by D. Dancer, coefficient of linear thermal expansion by V. Ringbloom, compressive strengths by W. Elban, A. Bertram, and

streak camera studies by N. Coleburn and L. Roslund of the Naval Ordnance Laboratory.

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TABLE 1

SIMULANT COMPOSITIONS

Simulant No	Ingredients	Composition (Wt. Percent)	Remarks
1	Melamine/Teflon T-30	62.7/37.3	Processing difficulties
2	Melamine/Kaolin/Teflon T-30	65.6/22.4/12.0	Processing difficulties
3	Melamine/Kaolin/Teflon T-30	65.6/22.4/12.0	Processing difficulties
4	Melamine/Kaolin/Teflon T-5	66.6/21.4/12.0	Excessive weight loss at 150°C
5	Melamine/Kaolin/Teflon T-5	67.6/20.4/12.0	Excessive weight loss at 150°C
6	Melamine/Kaolin/Teflon T-5	68.6/19.4/12.0	Excessive weight loss at 150°C
7	Terephthalic Acid/Kaolin/Teflon T-5	58.3/29.7/12.0	Excessive weight loss at 150°C
8	Melamine/Kaolin/Teflon T-5	52.1/35.9/13.0	Excessive weight loss at 150°C
9	Melamine/Kaolin/Teflon T-5	54.5/25.5/20.0	Excessive weight loss at 150°C
10	Melamine/Teflon 7C	70/30	Thermal conductivity too high
11	Melamine/Teflon 7C	62.3/37.7	Density adjustment
12	Teflon 7C/Vinylidene Fluoride	67/33	Thermal conductivity too high
13	Teflon 7C/Vinylidene Fluoride	26.5/73.5	Density adjustment
14	Teflon 7C/Vinylidene Fluoride	27/73	Thermal conductivity too low
15	Melamine/Teflon 7C/Vinylidene fluoride	7.5/28.5/64	Thermal conductivity too low
16	Terephthalic acid/Teflon 7C	68/32	Thermal conductivity too high
17	Melamine/Teflon 7C/Vinylidene fluoride	10/26/64	Examine effect of amount of melamine on
18	Melamine/Teflon 7C/Vinylidene fluoride	15/27/58	on thermal conductivity
19	Terephthalic acid/Teflon 7C/Vinylidene fluoride	7.5/28.5/64	Examine effect of substituting terephthalic acid for melamine on thermal conductivity
20	Melamine/Teflon 7C/Vinylidene fluoride	10/24/66	Selected composition

TABLE 2

THERMAL PROPERTIES OF SIMULANTS

	Run	Thermal Diffusivity cm^2/sec	Density g/cm^3	Specific Heat cal/gm/°C	Thermal Conductivity cal/cm/sec-°C
Simulant #15	1	1.03×10^{-3}	1.684	0.264	4.579×10^{-4}
	2	1.06×10^{-3}			4.713×10^{-4}
	Average	1.05×10^{-3}			4.668×10^{-4}
Simulant #16	1	4.94×10^{-3}*	1.686	0.270	22.488×10^{-4}
	2	4.22×10^{-3}			19.210×10^{-4}
	Average	4.22×10^{-3}			19.210×10^{-4}
Simulant #17	1	1.32×10^{-3}	1.718	0.239	5.420×10^{-4}
	2	1.26×10^{-3}			5.174×10^{-4}
	Average	1.29×10^{-3}			5.297×10^{-4}
Simulant #17 (after temp. cycling)	1	1.26×10^{-3}	1.68	0.278	5.885×10^{-4}
	2	1.23×10^{-3}			5.745×10^{-4}
		1.25×10^{-3}			5.838×10^{-4}
Simulant #18	1	1.33×10^{-3}	1.728	0.296	6.803×10^{-4}
	2	1.33×10^{-3}			6.803×10^{-4}
	Average	1.33×10^{-3}			6.803×10^{-4}
Simulant #19	Not Run				
Simulant #20	1	1.22×10^{-3}	1.708	0.278	5.793×10^{-4}

*Value not used. Chart speed considered too slow to give accurate result.

TABLE 3

COEFFICIENT OF LINEAR THERMAL EXPANSION

Material	Temp. Range (°C)	Coeff. of Expansion (cm/cm/°C)	Growth* (Percent)
HNS-II/Teflon 7C (90/10) (ID 1462)	8.3-97.6	6.68×10^{-5}	0.08
Vinylidene fluoride	19.8-97.5	18.71×10^{-5}	0.45
Teflon 7C (Pressed)	22.8-97.1	8.18×10^{-5}	0
Melamine	20.6-97.2	19.63×10^{-5}	1.67
Terephthalic acid	23.4-97.2	6.52×10^{-5}	0.16
Teflon (machined rod stock)	10.5-97.4	14.50×10^{-5}	0

*Percent of irreversible growth experienced on initial temperature cycle.
**Approximate value. Specimen cracked during measurement.

TABLE 4

COMPRESSIVE STRENGTH OF EXPLOSIVE PELLETS

Treatment	Compressive Strength (psi)			
	None		Heat Cycling *	
Compaction Pressure	25000 psi	30000 psi	25000 psi	30000 psi
HNS-II/Teflon 30 (ID 1378)	1828±35	1973±22	2253±44	2498±26
HNS-II/Teflon 7C (ID 1462)	2640±59	2728±125	2923±20	2936±89

*Specimens were heat cycled from ambient to 150°C for two cycles (holding the specimens at the 150°C temperature for two hours duration on each cycle).

TABLE 5

DETONATION VELOCITY TEST RESULTS OF THE HE EXPLOSIVE CHARGES

Charge Size (lb)*	Charge Number	Bendix EP Number	Charge Radius (inches)	Steady Detonation Velocity (mm/μsec)
1/8	1	EP-3	0.680	**
1/4	10	EP-2	0.860	7.02
1/2	3	EP-7	1.085	6.62
1	4	EP-6	1.365	6.67
3	13	EP-5	1.975	6.77

*Of the 5 charges tested, all except the 1/8-lb charge had cracks.
**Charge initiated, smear camera trace lost.

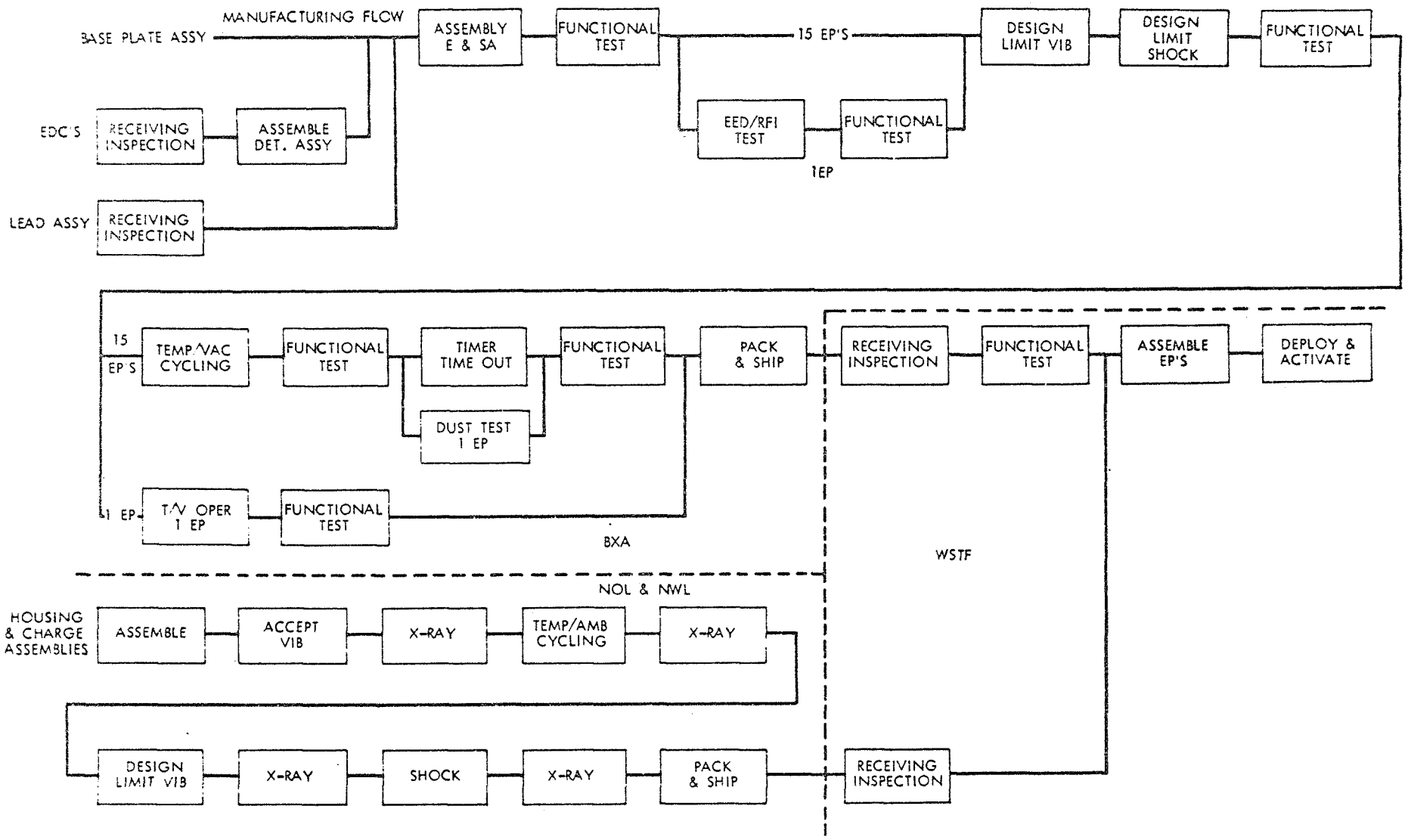


FIG. 1 LSP EXPLOSIVE PACKAGE PROTOTYPE HARDWARE FLOW

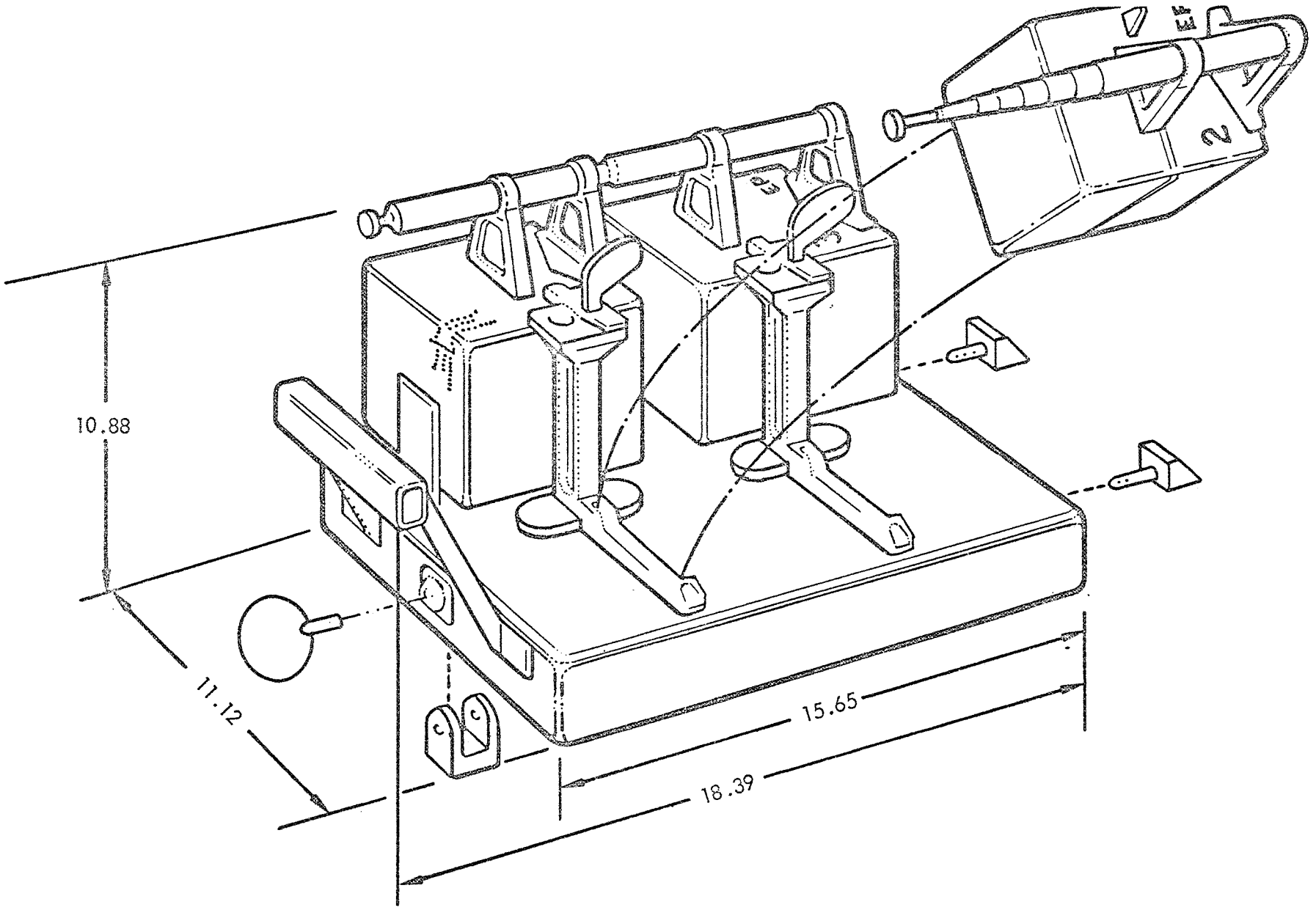


FIG. 2 EXPLOSIVE PACKAGE TRANSPORT MODULE (BENDIX AEROSPACE)

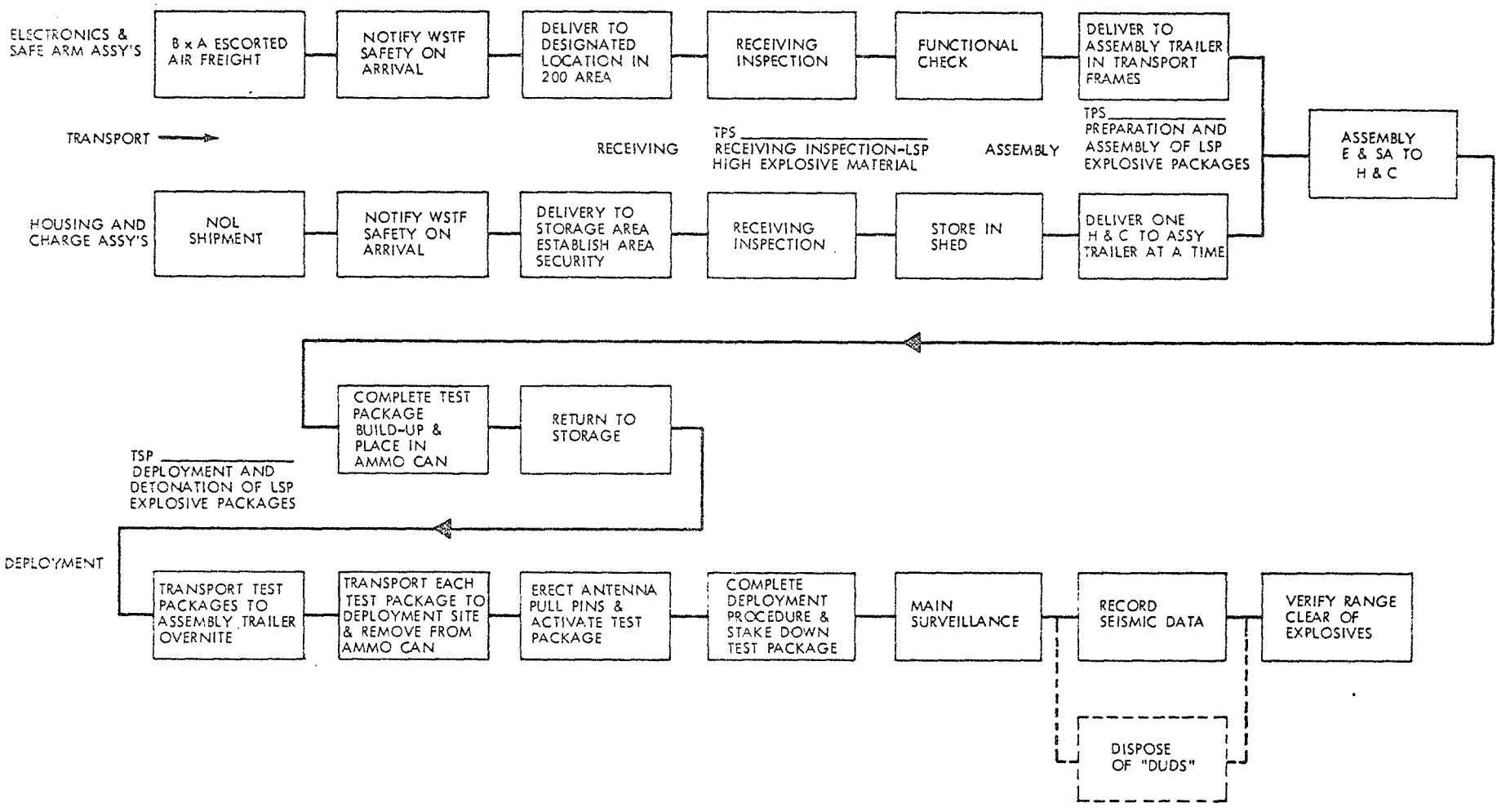
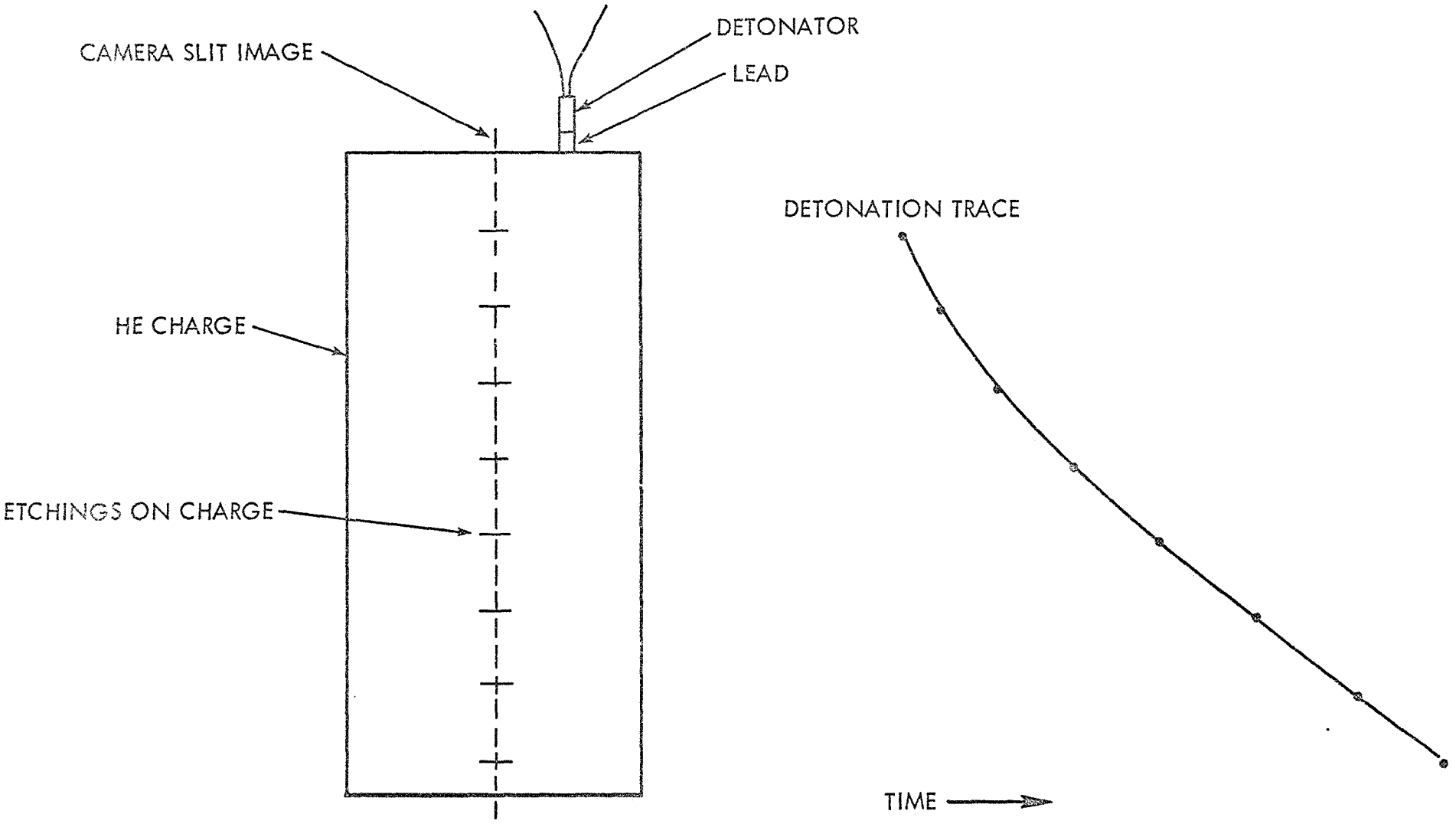


FIG. 3 LSP-EXPLOSIVE TEST PACKAGE FLOW-WSTF

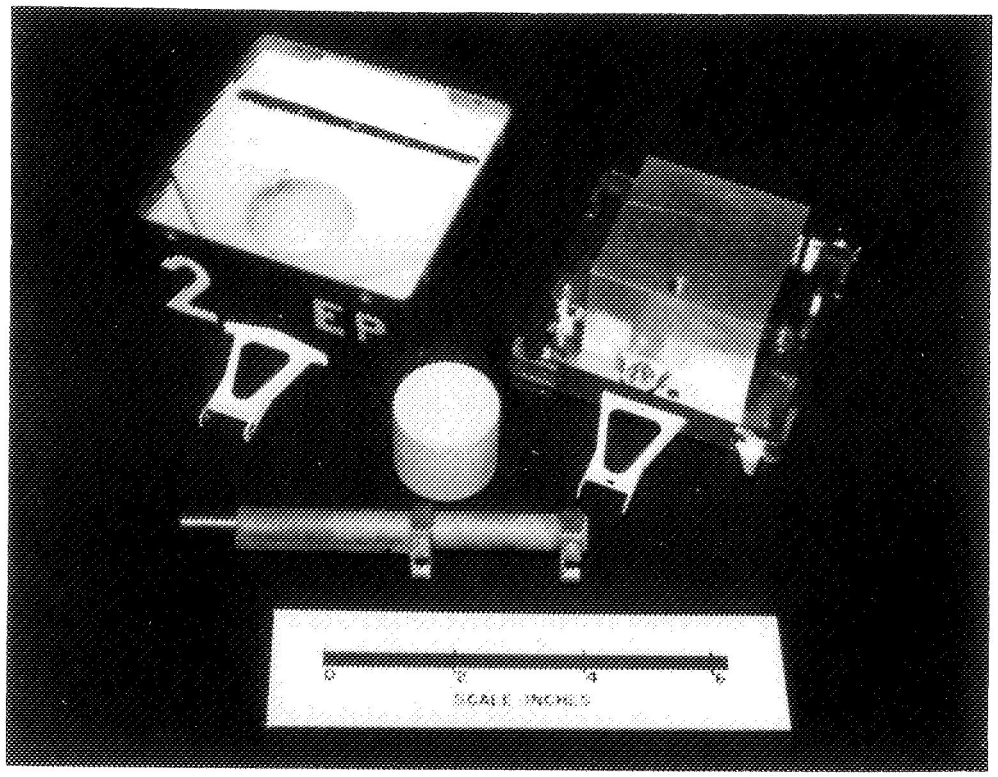


(a) TEST ARRANGEMENT

(b) TYPICAL TIME-DISTANCE VELOCITY TRACE

FIG. 4 DETONATION VELOCITY MEASUREMENT TECHNIQUE

A



B

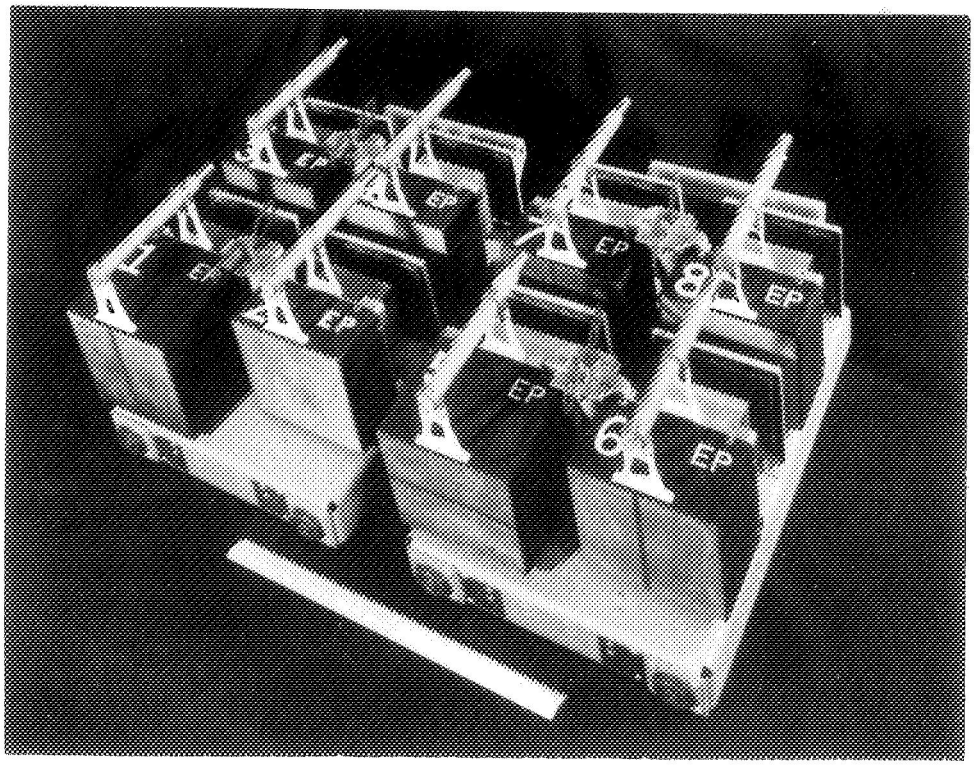


FIG. 5 EXPLOSIVE HARDWARE AND EXPLOSIVE PACKAGE TRANSPORT ASSEMBLY FOR LSPE

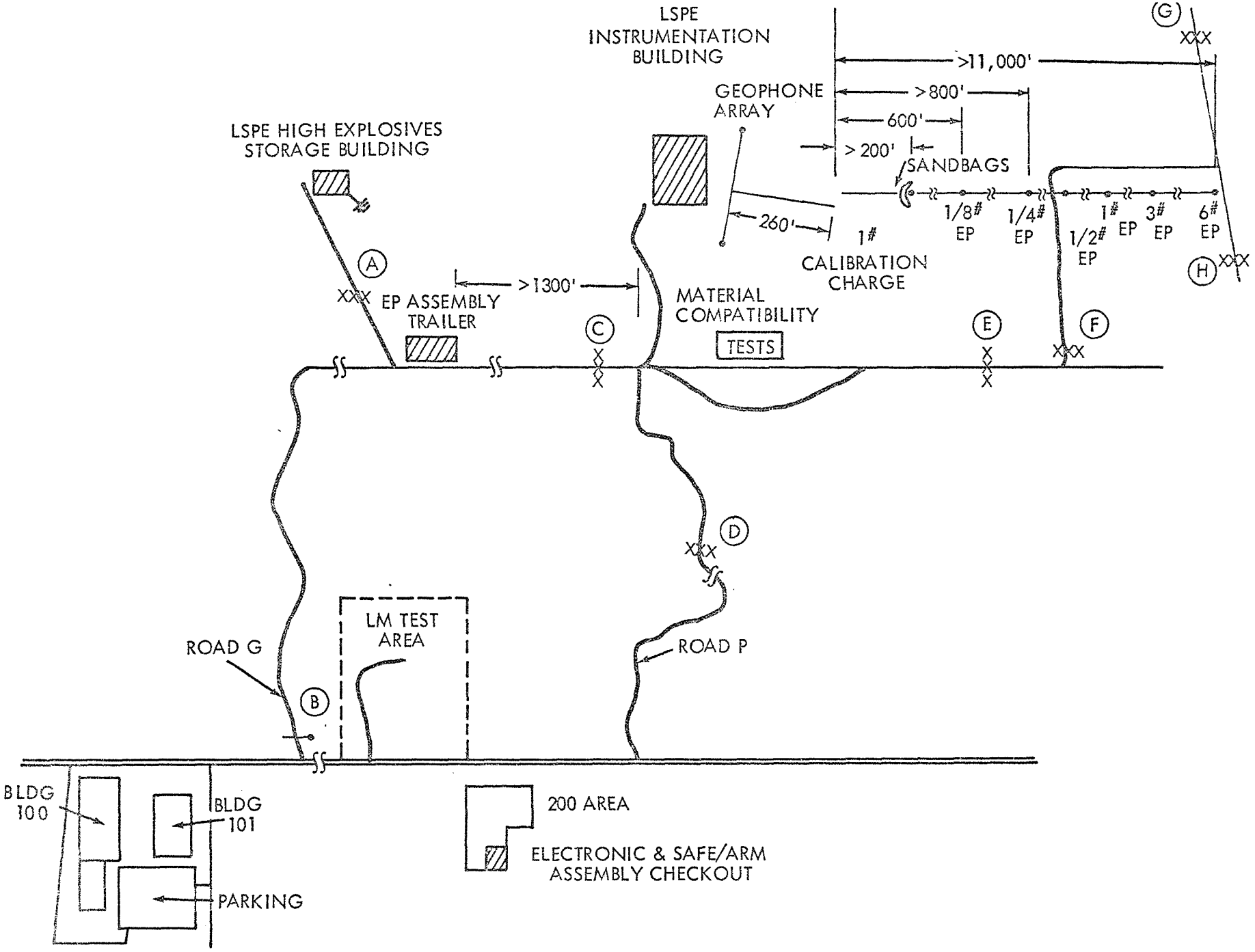


FIG. 6 LSPE FIELD TEST SITE WHITE SANDS TEST FACILITY

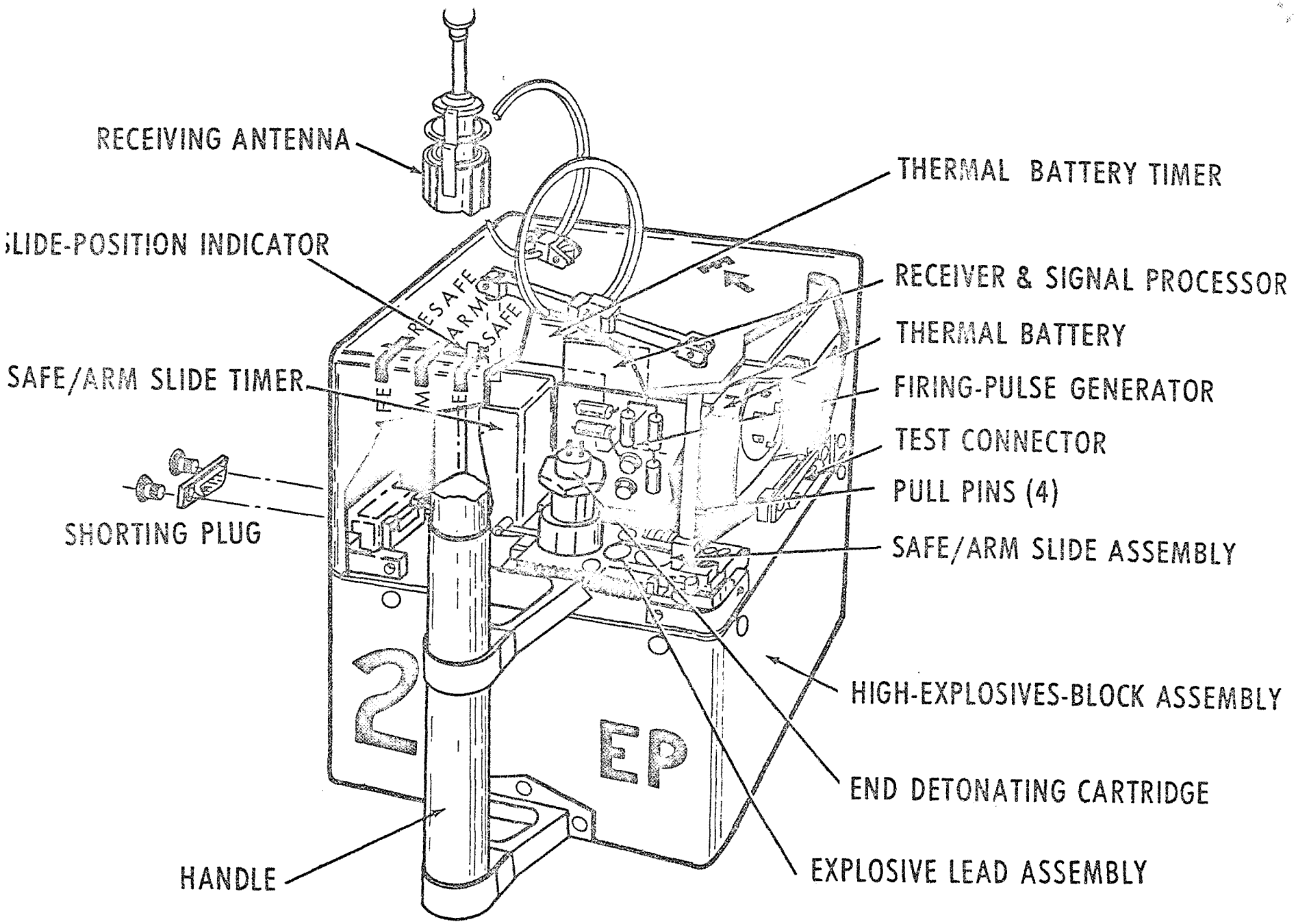


FIG. 7 LSPE EXPLOSIVE PACKAGE ASSEMBLY (BENDIX AEROSPACE)

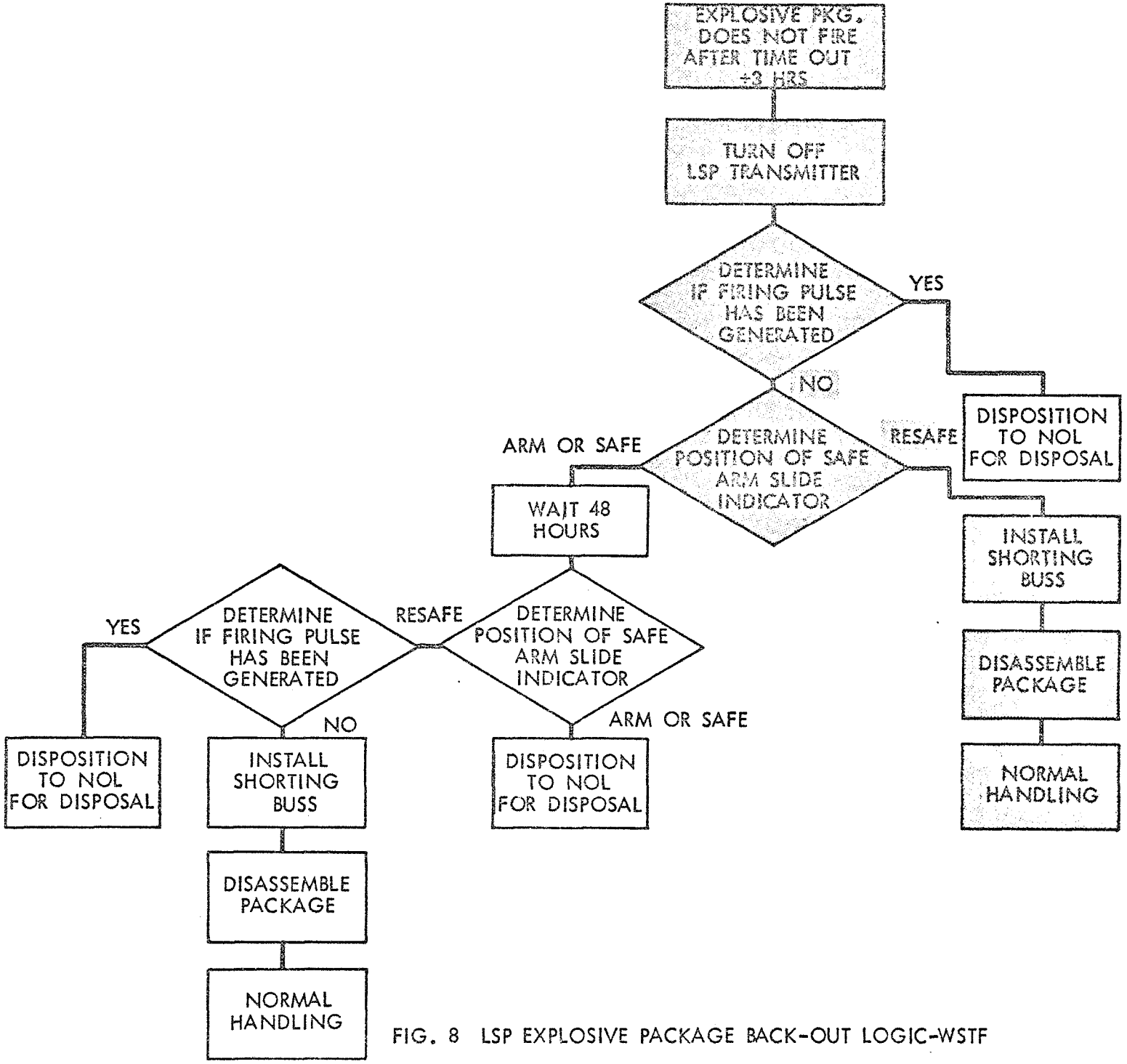


FIG. 8 LSP EXPLOSIVE PACKAGE BACK-OUT LOGIC-WSTF